# Shallow Ocean Bottom BRDF Prediction, Modeling, and Inversion via Simulation with Surface/Volume Data Derived from X-ray Tomography

G. C. Boynton
Physics Dept, University of Miami, PO Box 248046, Coral Gables, FL 33124
phone: (305) 284-7140 fax: (305) 284-4222 email: chris@physics.miami.edu

K. J. Voss
Physics Dept, University of Miami, PO Box 248046, Coral Gables, FL 33124
phone: (305) 284-7140 fax: (305) 284-4222 email: voss@physics.miami.edu

Award Number: N00014- 07-1-0308
http://optics.physics.miami.edu/brdf/brdf.htm

## LONG-TERM GOALS

We are investigating the measurable features in the BRDF (Bi-directional Reflectance Distribution Function) of benthic surfaces made of natural sediments and how that is influenced by the morphology of the sediment grain composition. If the measured BRDF shows features which can be numerically derived from the physical properties such as size and shape of the sediment material, then we should be able to invert BRDF data to obtain significant characterizations of the natural sediment properties.

## OBJECTIVES

Extend current numerical BRDF ray tracing techniques to deal with natural sediments via input of sediment grain data from x-ray CT measurements. Discover if the BRDF data can be inverted to give information about grain size, morphology and interstitial spacing.

## APPROACH

We are combining three areas of expertise, Ken Voss is measuring the BRDF of natural sediments, Allen Reed is aquiring detailed x-ray CT (computerized tomographic) data of natural sediments, and Chris Boynton is numerically deriving the BRDF via optical ray tracing of the sediment grain morphology (position, size, surface and orientation) obtained from the x-ray tomography data.

We are applying these three separate techniques to surfaces composed of three to four distinct natural sediment types, and one surface composed of spheres. We are using the spheres to understand and minimize the errors due to sub-resolution representation of the surfaces of the grains. Show in Figure 1 is an example of a natural sediment composed of mostly Carbonate Ooids.

# Report Documentation Page

*Form Approved*
*OMB No. 0704-0188*

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

| | | |
|---|---|---|
| 1. REPORT DATE<br>**2008** | 2. REPORT TYPE | 3. DATES COVERED<br>**00-00-2008 to 00-00-2008** |

| | |
|---|---|
| 4. TITLE AND SUBTITLE<br>**Shallow Ocean Bottom BRDF Prediction, Modeling, and Inversion via Simulation with Surface/Volume Data Derived from X-ray Tomography** | 5a. CONTRACT NUMBER<br>5b. GRANT NUMBER<br>5c. PROGRAM ELEMENT NUMBER |
| 6. AUTHOR(S) | 5d. PROJECT NUMBER<br>5e. TASK NUMBER<br>5f. WORK UNIT NUMBER |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)<br>**University of Miami,Physics Dept,PO Box 248046,Coral Gables,FL,33124** | 8. PERFORMING ORGANIZATION REPORT NUMBER |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) | 10. SPONSOR/MONITOR’S ACRONYM(S)<br>11. SPONSOR/MONITOR’S REPORT NUMBER(S) |

12. DISTRIBUTION/AVAILABILITY STATEMENT
**Approved for public release; distribution unlimited**

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON |
|---|---|---|---|---|---|
| a. REPORT<br>**unclassified** | b. ABSTRACT<br>**unclassified** | c. THIS PAGE<br>**unclassified** | **Same as Report (SAR)** | **8** | |

**Standard Form 298 (Rev. 8-98)**
Prescribed by ANSI Std Z39-18

***Figure 1. Carbonate Ooid sample sediment surface***

***[Image: a sample surface composed of Carbonate Ooids magnified to show the polished nature of the individual surfaces, the general ovoid shape and the general size distribution of the grains which appear to vary by no more than a factor of two in linear dimension.]***

Ken Voss at the University of Miami Physics Department is using the previously developed BRDF meter capable of in-situ underwater and laboratory measurements [1] to measure the BRDF of the sample surfaces.

Allen Reed at NRL Stennis Space Center is aquiring the X-ray tomographic data from the prepared and optically measured sediments. The X-Ray tomographic technique produces data that gives a fine scale three dimensional description of the surface geometry of each individual grain and the interstitial spaces. Below are graphically rendered examples of  the data from the X-ray CT device. Figure 2 shows a cubic section of the data revealing the detail of the grain and interstitial spacing. Figure 3 shows an individual grain's data extracted from the data represented in Figure 2 indicating the detail of the individual grains surface shape obtained from the x-ray CT data.

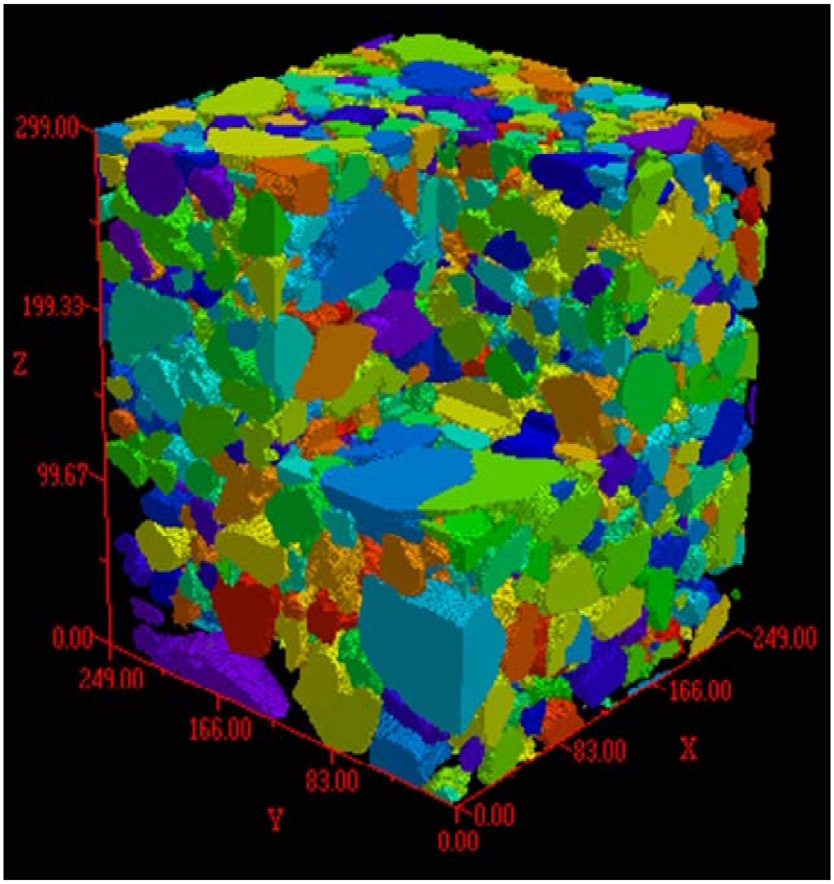


***Figure 2. Example section of x-ray CT data provided by Allen Reed, NRL SSC.***

***[Image: three dimensional cubic section of natural sediment showing individual grains and interstitial spaces]***

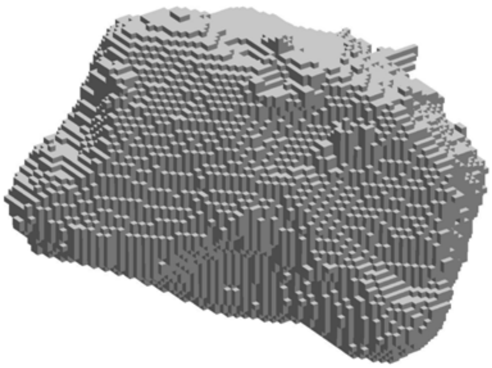

***Figure 3. Example x-ray CT data of individual grain in Figure 2.***

***[Image: individual grain surface and apparent volume shown in a three dimensional representation]***

Chris Boynton at the University of Miami Physics Department is doing the numerical ray tracing derivation of the BRDF using the grain data from the X-ray tomography measurements of the sediments. Below is an example of the numerically derived BRDF for surface composed of packed spheres.

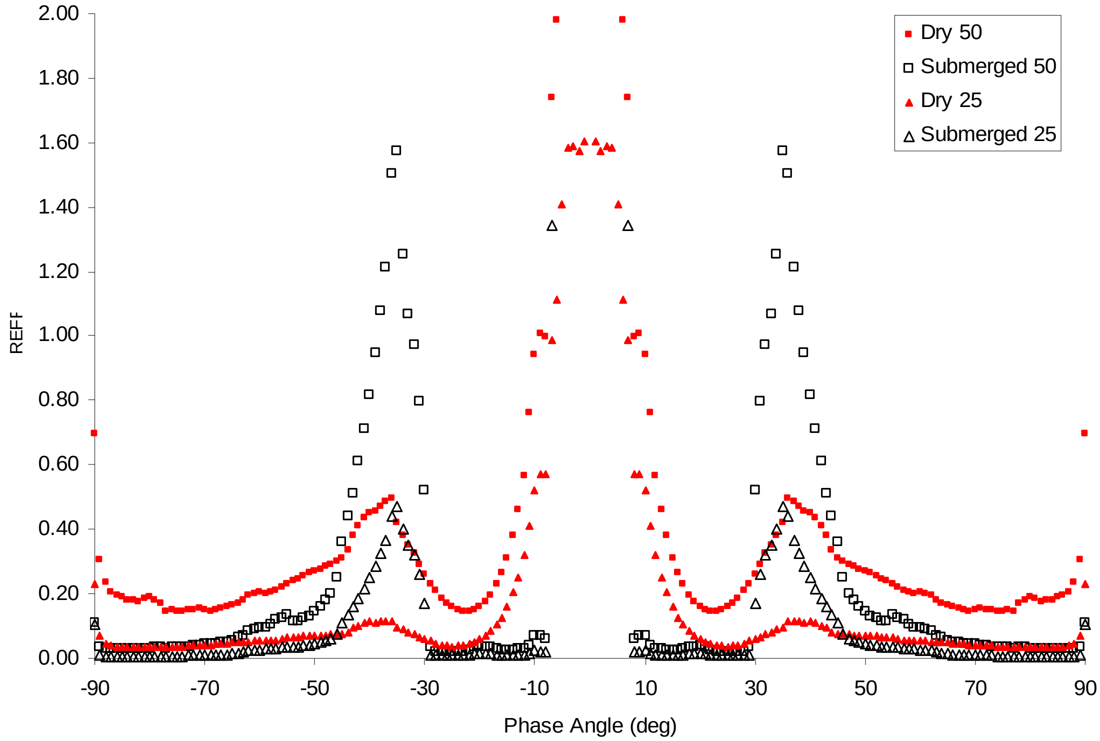


***Figure 4. Calculated REFF (BRDF normalized to the BRDF of a 100% lambertian reflector ) versus phase angle (0 deg phase angle, direct backscattering) for mixtures of lambertian and clear spheres in a regular close packed array when dry or submerged in water. Illumination is at 0 degrees.***

***[Graph: illustrating fine detail in BRDF data available from numerical calculation and the darkening effect of submerging mixtures of clear and "gray" particles]***

## WORK COMPLETED

We've placed our five samples (composite natural sand, ooids, quartz sand, polystyrene spheres, and flocculent benthic sediments) into the previously manufactured sample holders for analysis by both our optical BRDF instrument and the Micro-focus Xray Computerized Tomography (MXCT) instrument at NRL SSC. The MXCT instrument requires preparation of the sample by embedding it in an epoxy resin. To preserve the condition of the samples as closely as possible between the optical BRDF measurement and the MXCT analysis we placed the five samples in their dual purpose holders, measured their optical BRDF and then immediately applied the epoxy resin to set them for the NRL MXCT instrument. Subsequent scans with the MXCT instrument have revealed problems with the custom instrument that NRL is repairing now.

**RESULTS**

We are satisfied that the new dual purpose sample holders have not interfered with the optical measurements of the BRDF. The BRDF of the ooid, natural sand, and spheres samples have been obtained before under different circumstances and the new measurements show no surprises, matching our older measurements closely.

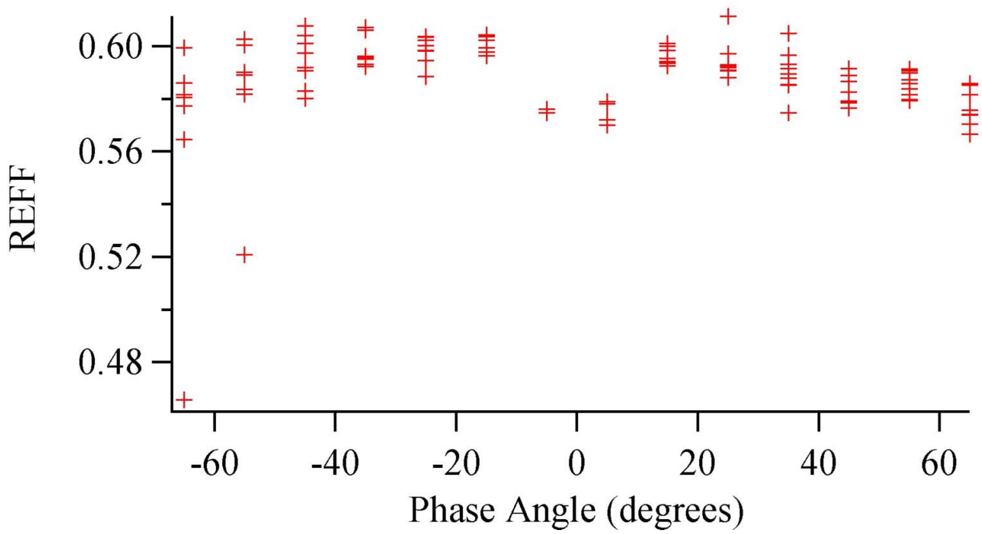


***Figure 5. Ooid sample, 0 deg incidence***

As seen in the graphs in Figures 5 and 6, ooids show a nearly lambertian response at normal incidence, and the expected hot spots in both backward and specular scatering phase angles. (The graphs show REFF, which is the BRDF normalized to a lambertian surface. We also use phase angle, which is the angle relative to the incident illumination, 0 phase angle is direct back scattering)

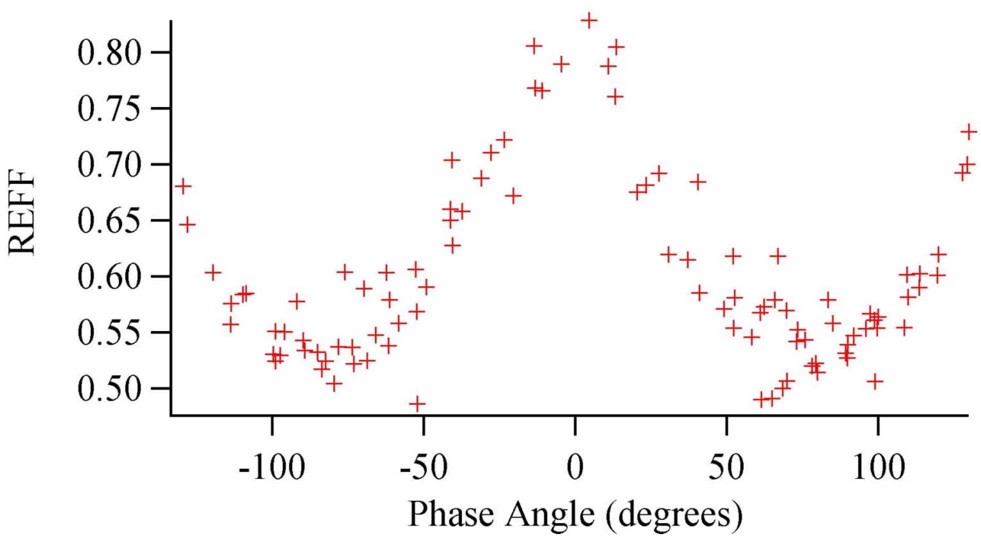


***Figure 6. Ooid sample, 65 degree incidence***

We’ve included quartz sands in our samples because of their observably different morphology and reflectance. The BRDF (Figures 7 and 8) of this sample shows the nearly lambertian reflectance at 0 degrees incident illumination, but shows a more pronounced variation between the hot spot and specular reflectance at 65 degrees incident illumination, with the backscattering hotspot relatively reduced.

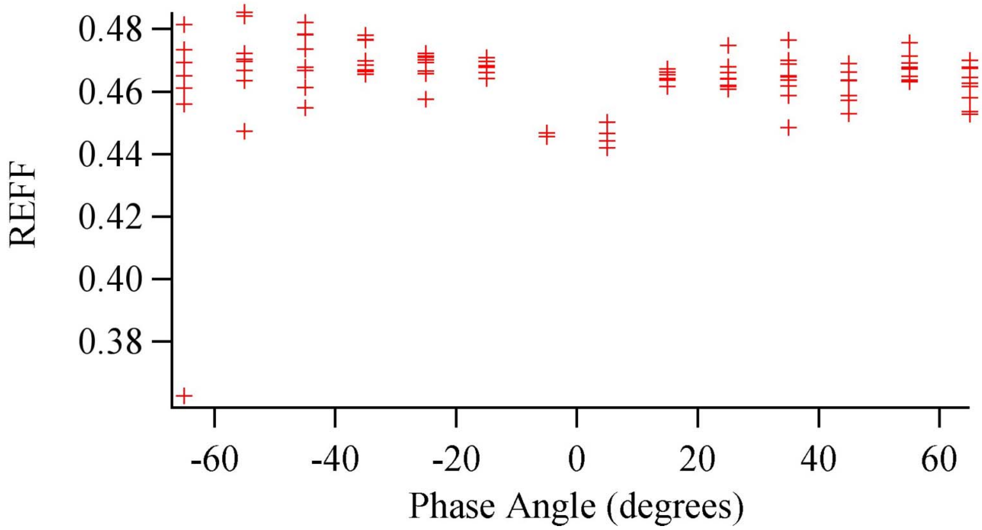


***Figure 7. Quartz Sand, 0 degree incidence***

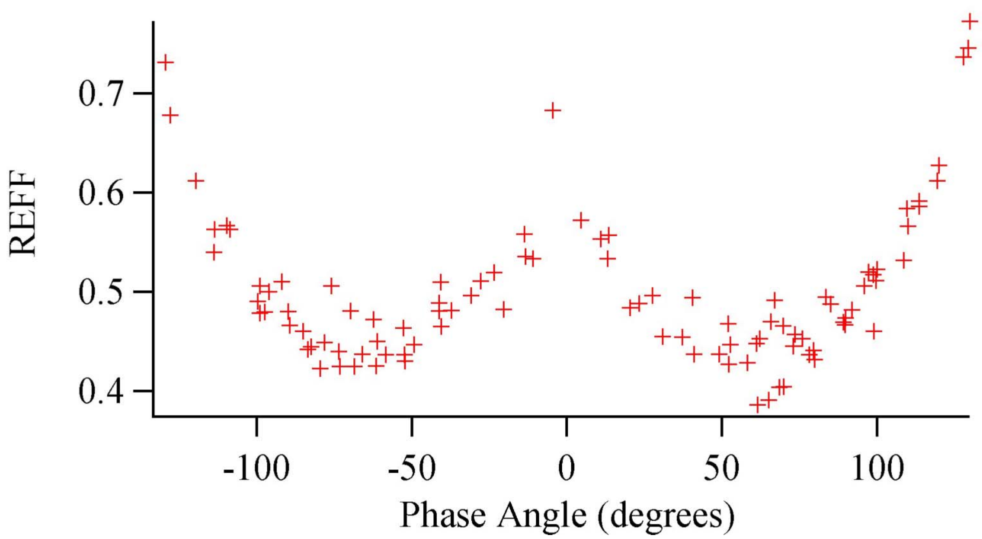


***Figure 8. Quartz sand, 65 degree incidence***

Our highest risk sample, the floculent natural benthic material, shows some distinct features in the optical BRDF measurements. This sample is “high risk” because we are pushing the envelope of the information that the MXCT instrument can provide. The sample has many very small particles/grains and the necessary sample volume combined with the sample resolution may be beyond the capabilties of the MXCT instrument.

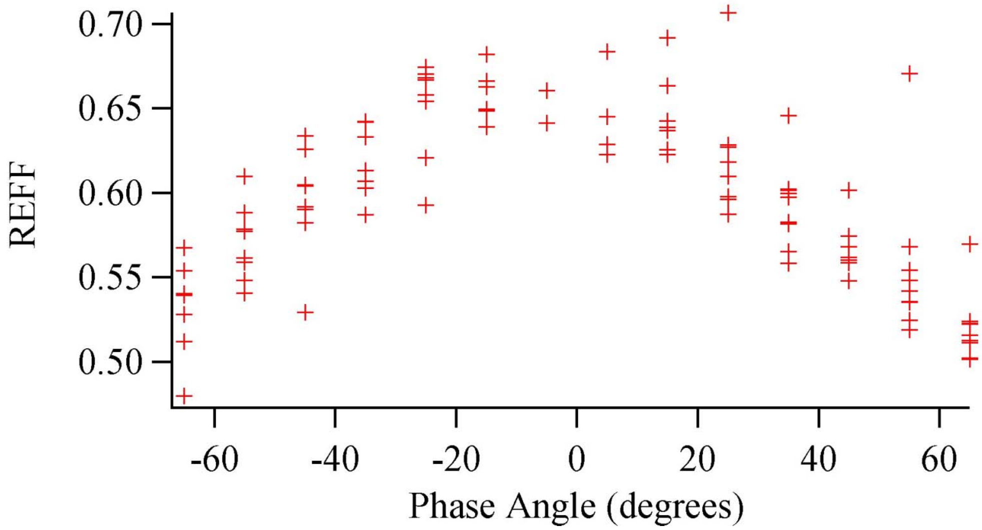


***Figure 9. Flocculent sample, 0 deg incidence***

Figures 9 and 10 show the REFF for the floculent sample. Notice the distinctly less lambertian profile at 0 degress illumination. The graph in Figure 10 shows a very strong hot spot in the backward direction

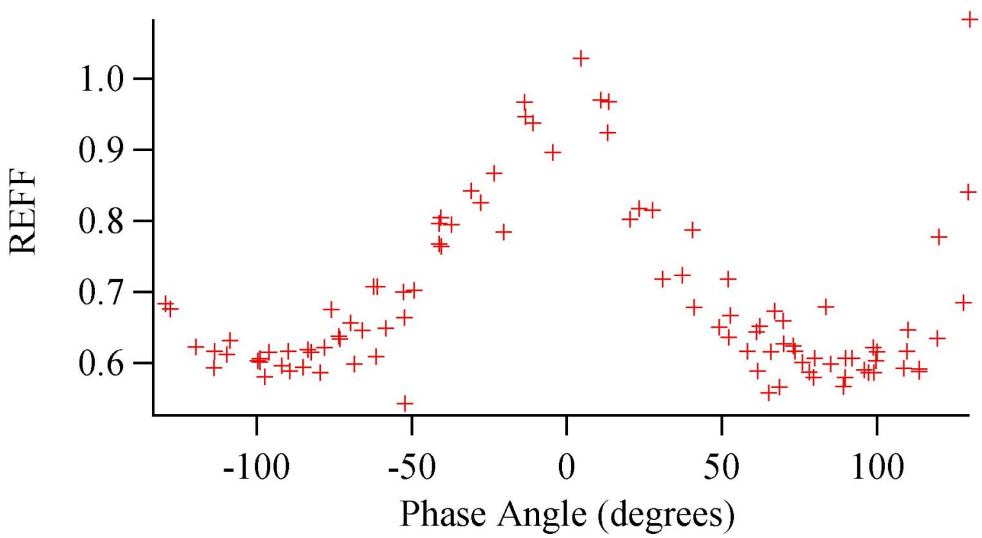


***Figure 10. Flocculent sample, 65 deg incidence***

## IMPACT/APPLICATIONS

If the BRDF is sufficiently sensitive to bulk sediment morphology, then it maybe invertible allowing for prediction of local sediment morphology via remote sensing.

## RELATED PROJECTS

None.

## REFERENCES

[1] Voss, K.J. et al, “Instrument to measure the Bidirectional reflectance distribution function of surfaces”, Applied Optics **39,** 6197-6206 (2000)